Journal of Theoretical Biology 317 (2013) 126–132

Contents lists available at SciVerse ScienceDirect

Journal of Theoretical Biology

journal homepage: www.elsevier.com/locate/yjtbi

Coexistence of fraternity and egoism for spatial social dilemmas

György Szabó [a,*], Attila Szolnoki [a], Lilla Czakó [b]

[a] Institute of Technical Physics and Materials Science, Research Centre for Natural Sciences, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary
[b] Roland Eötvös University, Institute of Physics, Pázmány P. sétány 1/A, H-1117 Budapest, Hungary

HIGHLIGHTS

- ► Spatial evolutionary games are extended by fraternity.
- ► Behaviors are explored by numerical simulations and stability analysis.
- ► Coexistence of fraternity and selfishness is demonstrated.
- ► Role-separating spatial patterns can promote cooperation.

ARTICLE INFO

Article history:
Received 17 August 2012
Received in revised form
6 October 2012
Accepted 8 October 2012
Available online 16 October 2012

Keywords:
Evolutionary games
Social dilemmas
Egoism
Fraternity

ABSTRACT

We have studied an evolutionary game with spatially arranged players who can choose one of the two strategies (named cooperation and defection for social dilemmas) when playing with their neighbors. In addition to the application of the usual strategies in the present model the players are also characterized by one of the two extreme personal features representing the egoist or fraternal behavior. During the evolution each player can modify both her own strategy and/or personal feature via a myopic update process in order to improve her utility. The results of numerical simulations and stability analysis are summarized in phase diagrams representing a wide scale of spatially ordered distribution of strategies and personal features when varying the payoff parameters. In most of the cases only two of the four possible options prevail and may form sublattice ordered spatial structure. The evolutionary advantage of the fraternal attitude is demonstrated within a large range of payoff parameters including the region of prisoner's dilemma where egoist defectors and fraternal cooperators form a role-separating chessboard like pattern.

1. Introduction

Multi-agent game theoretical models give us a general mathematical tool to describe real-life situations in human societies and to study biological systems when varying the interactions, evolutionary rules, and connectivity structure among the players (Maynard Smith, 1982; Nowak, 2006a; Sigmund, 2010; Pacheco et al., 2008). In many cases the interactions are approximated by the sum of pair interactions between neighboring (equivalent) players distributed on the sites of a lattice or graph (for a survey see Nowak and May, 1993; Szabó and Fáth, 2007; Perc and Szolnoki, 2010). The simplest spatial versions of two-strategy games have demonstrated new outcomes of evolutionary process, which are missing if well-mixed players are postulated.

To give an example, the most exhaustively studied symmetric two-person two-strategy game is the so-called Prisoner's Dilemma (PD) game where the equivalent players can choose cooperation or defection. For mutual cooperation (defection) both players receive a payoff R (P) while for their opposite decisions the cooperator (defector) gains S (T). For the PD game the payoffs satisfy the conditions: $S<P<R<T$, that enforces both selfish players to choose defection (representing the state called the "tragedy of the commons", Hardin, 1968) meanwhile the mutual cooperation would be more beneficial for the players. Being trapped in the state of mutual defection is in stark contrast to our everyday experience of high level of cooperation. To resolve this discrepancy several cooperation supporting conditions and mechanisms were identified (Nowak, 2006b; Pacheco et al., 2006a; Fu et al., 2009, 2012; Poncela et al., 2009; Pacheco et al., 2006b; Tomassini et al., 2010; Gómez-Gardeñes et al., 2008; Fort, 2008; Perc, 2011; Vukov et al., 2011; Pinheiro et al., 2012). Alternative ways to explain the emergence of cooperation are originated from the observation that humans follow more complex behavior that cannot be well described by simple unconditional cooperator and defector acts. Human experiments (Fehr and Falk, 2002; Camerer, 2003; Nowak, 2006a; Sigmund, 2010; Traulsen et al., 2010) highlighted that

* Corresponding author. Tel./fax: +36 1 3922678.
E-mail address: szabo@mfa.kfki.hu (G. Szabó).

0022-5193/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jtbi.2012.10.014

individuals possess different personal features or emotions (Szolnoki et al., 2011), e.g., selfish (von Neumann and Morgenstern, 1944), altruistic (Sigmund et al., 2002), fraternal (Scheuring, 2010; Szabó and Szolnoki, 2011), punishing (Clutton-Brock and Parker, 1995; Fehr and Gächter, 2002; Kurzban and Houser, 2005), reciprocative (Berg et al., 1995), envy (Garay and Mori, 2011; Szolnoki et al., 2011), just to name a few examples. Following this avenue, now we introduce a spatial model where players are not limited to the use of the pure cooperator and defector strategies but they are also motivated by an additional personal feature characterizing their egoist or fraternal attitude. Accordingly, the present work generalizes and extends previous specific efforts about the consequences of collective decisions (Szabó et al., 2010) and other-regarding preferences for a uniform level of fraternal behavior (Szabó and Szolnoki, 2011). Here it is worth mentioning that the fraternal behavior can prevent the society from falling into the "tragedy of commons" state. Consequently, the advantage of the fraternal behavior can be interpreted as an evolutionary driving force supporting societies to maintain/develop the altruistic personal features. Studying the present model we wish to explore the consequences of the spatial competition (evolutionary process) between the above described strategy profiles. It is emphasized, furthermore, that for the quantum games (Abal et al., 2008; Li et al., 2011) the players exhibit a behavior similar to those played by fraternal players.

For the sake of comparison the present analysis is also performed for all 2×2 social dilemmas games [including PD, Hawk-Dove (HD) and Stag-Hunt (SH) games] when varying the values of T and S (for $R=1$ and $P=0$ without loss of generality). Finally we mention that the present four-strategy model is analogous to those cases when the spatial social dilemmas are studied by considering voluntary participation (Szabó and Hauert, 2002), punishments (Rand et al., 2009; Sekiguchi and Nakamaru, 2009; Helbing et al., 2010), and the use of sophisticated strategies like Tit-for-tat (Nowak and Sigmund, 1992) or others (Ohtsuki, 2004; Ohtsuki and Iwasa, 2006; Rand et al., 2009).

Due to the biological motivations (Maynard Smith, 1982) in the early evolutionary games the time-dependence of the strategy distribution is controlled by the imitation of a better performing neighbor. In human societies, however, we can assume more intelligent players who are capable to evaluate their fictitious payoff variation when modifying strategy (Sysi-Aho et al., 2005; Szabó and Fáth, 2007). The corresponding so-called myopic evolutionary rule is analogous to the Glauber (1963) dynamics used frequently in the investigation of stationary states and dynamical processes for the kinetic Ising model (Binder and Hermann, 1988). In biological systems the latter mechanism can be interpreted as the survival of possible mutants with a probability increasing with the current fitness. Contrary to the imitation of a neighbor, the mentioned myopic dynamical rule permits the formation of sublattice ordered distribution of strategies (and/or personalities) resembling the anti-ferromagnetic structure in the Ising systems. For the case of spatial PD the chessboard like arrangement of cooperators and defectors is favored if $T+S>2R$. This latter criterion coincides with those one when the players have the highest average income in the repeated two-person PD game if they alternate cooperation and defection in opposite phase.

It will be demonstrated that the present model exhibits different disordered and sublattice ordered spatial arrangements as well as phase transitions when varying the payoff parameters for several fixed levels of noise. It means that in contrary to preliminary/naive expectation the fraternal players may survive in the presence of egoist competitors.

The rest of this paper is organized as follows. First, we describe our four-strategy lattice model. The results of Monte Carlo (MC) simulations at a fixed noise level are detailed in Section 3 while phase diagram in the low noise limit are discussed in Section 4. This diagram can be obtained by means of stability analysis of the possible two-strategy phases against the point defects. The essence of this method and an analytical estimation for the direction of interfacial invasion between the mentioned phases are briefly described in Section 5. Finally, we summarize our main finding and discuss their implications.

2. The model

In the present model the players are located on the sites of a square lattice with $L\times L$ sites. The undesired effects of boundaries are eliminated by using periodic boundary conditions in the simulations. At each site x four types of players are distinguished, namely, $s_x=D_e$, C_e, D_f, and C_f. In our notation D_e and C_e refer to egoist defector and cooperator while D_f and C_f denote fraternal defector and cooperator for the PD games. For other types of games (e.g., HD or SH) we will use the above mentioned abbreviations of types that we call strategies henceforth. In the mathematical formulation of utilities these strategies are denoted by the following unit vectors:

$$D_e=\begin{pmatrix}1\\0\\0\\0\end{pmatrix},\quad C_e=\begin{pmatrix}0\\1\\0\\0\end{pmatrix},\quad D_f=\begin{pmatrix}0\\0\\1\\0\end{pmatrix},\quad C_f=\begin{pmatrix}0\\0\\0\\1\end{pmatrix}. \tag{1}$$

The utility $U(\mathbf{s}_x)$ of the player x (with a strategy $\mathbf{s}_x$) comes from games with her four nearest neighbors and can be expressed by the following sum of matrix products:

$$U(\mathbf{s}_x)=\sum_{\delta}\mathbf{s}_x\cdot\mathbf{A}\mathbf{s}_{x+\delta}. \tag{2}$$

Here the summation runs over the four nearest neighboring sites of x and the payoff matrix $\mathbf{A}$ is given as

$$\mathbf{A}=\begin{pmatrix}0 & T & 0 & T\\ S & 1 & S & 1\\ 0 & \sigma & 0 & \sigma\\ \sigma & 1 & \sigma & 1\end{pmatrix}, \tag{3}$$

where $\sigma=(T+S)/2$. The matrix elements in the upper-left 2×2 block of the whole payoff matrix define the payoffs between egoist players (D_e and C_e). The present notation is adopted from the literature of social dilemmas where T refers to "temptation to choose defection", S is abbreviation of " sucker's payoff", the "punishment for mutual defection" is chosen to be zero (*i.e.*, $P=0$), and the "reward for mutual cooperation" is set $R=1$ for a suitable unit. In contrary to the egoist individuals the fraternal players revalue their payoffs by assuming equal sharing of the common income. In other words, the fraternal players wish to maximize their common income therefore their utility is expressed by a partnership game (Hofbauer and Sigmund, 1998) represented by the lower-right 2×2 block of the payoff matrix (3). It is emphasized that the utility of a given player is based on her own character and is independent of the personal feature (egoist or fraternal) of the co-players. Notice, furthermore, that for the present symmetric game the pair of egoist and fraternal players have the same utility (1 or 0) if both follow the same strategy (cooperation or defection).

The main advantage of the present approach is that we have only two payoff parameters (T and S) when studying the competition between the egoist and fraternal players. Further advantage of this parametrization is that the spatial evolutionary game with only egoist (or fraternal) players were already studied for myopic strategy update at arbitrary payoffs (Szabó et al., 2010; Szabó and Szolnoki, 2011) and the results will serve as references for later